ELEMENTARY SCIENCE IN THE HIGH SCHOOL[1]

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A high-school course in elementary science is a thing so unusual that a justification of its existence fittingly precedes any discussion of what its content should be.

In the average high school of the present time the heavy requirements for graduation are for the study of English, languages, history, and mathematics—as everyone knows. Science, if required at all, is represented by a scanty year, in rare cases by two years, and sometimes, as in the school I represent, by but one half-year's work. The explanation of this limitation of science requirements is, as we all know, due largely to the character of the entrance requirements of our colleges and universities. Anything which the pupil gets beyond this required work he frequently has difficulty in crowding into his course because of the other studies which he must pursue in order to be able to enter, without condition, the college of his choice. The result of this state of affairs is that in many schools a large proportion of the graduates have never had any work in more than one science, and that in those where no requirement in science would exist were there no state law requiring physiology, pupils frequently are graduated without having had any other scientific work than that given in the course involving physiology.

In schools in which the requirement is small, it seems to some of us highly desirable that this requirement should consist of a semester's or a year's study of elementary science, which would include a certain amount of work in chemistry, physics, botany, and, if the law requires it, physiology; if not, zoölogy is to be preferred. In a year's work some of the elements of earth science might well be included. Such a course would make it

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possible to acquaint the boys and girls with certain basic scientific principles, and to give them a knowledge of at least a few of the most ordinary scientific phenomena.

In schools where the conditions are better and where two years of science are required for graduation, there is quite another argument for such a course, one which, however, holds good also for the schools of greater limitation; namely, that for the understanding of any physiology, plant or animal, and for effective work in physiography, there is necessary a certain amount of elementary chemistry and physics. For instance, when the evidences of respiration are to be studied, precious time will not have to be spent upon discovering the properties of the gases concerned, and by pupils who have for themselves obtained evidence that heat is energy of molecular motion, the evolution of heat during this process will be more readily understood and its value will be better appreciated. These same elementary facts and principles are as necessary for the understanding of physiographical processes as for intelligent comprehension of life-processes. In addition to the saving of time thus involved there is avoided a certain evil consequent upon teaching the chemical and physical facts just at the time when they are needed for understanding of some life-process. Presenting them as isolated facts at such times undoubtedly results in the pupil's obtaining a distorted perspective. These things should form a mental background, a magazine of knowledge upon which he can draw for aid in interpreting phenomena new to him.

If this work is properly done it can work no detriment to the student when he afterward elects an entire year of either physics or chemistry. (Indeed we have the witness of our instructor in chemistry that time is saved by it.) Moreover, the brief but pleasant taste of each of these subjects which he gets in the elementary work may be the means of arousing in him sufficient interest in them so that he will elect one or both to be a part of his course of study. This same argument is to be made for each of the other subjects presented in such a course. An interest in plants or animals may be engendered which will impel him to their further study. And if such interest is not aroused

and the youth departs from the high school without further scientific study, at least he will have been armed with the most elementary knowledge of the things and forces which surround him, and, I hold this no less important though I mention it so tardily, he will have received a little training in habits of accurate observation, of thinking to conclusions; he will have been led at least a few times into the attitude of scientific inquiry.

Such a course has been much experimented upon in the last few years in the Oak Park High School, and while it has not yet attained perfectly definite shape in all its parts, the evolution of the course is nearing its completion. Of course, no live course in science is ever absolutely defined, and it is to be hoped that the time will never come when this course will be rigidly outlined, but it has reached the place where its content is approximately determined.

It is given in the first year of the high-school course. No other science can be elected until credit in this course has been received. It runs throughout the year, each section meeting on alternate days. In this way each class has one double period for laboratory work and one single period for discussion and quizzing every week, and on alternate weeks two such recitation periods. This plan of separating the periods of instruction is especially good for that part of the work which is concerned with chemistry and physics, for, in those weeks so many new ideas, ideas rather difficult for him to grasp, are being presented to the child, that they must needs be fed to him somewhat slowly, in order that he may have time for digestion and assimilation of each in its own turn. Too great haste results in an attack of mental dyspepsia and utter inability to make use of any of the material. The very method of thinking is new. Too continuous exercise of this sort would weary him. His imagination also needs time to grow in.

The order of the subjects as at present outlined is, physics, chemistry, physiology, and botany. In the spring, before or in the midst of the botany, the life-history of the frog or the toad, and, at the end, the life-history of the mosquito are to be

introduced, these two studies being the only ones of a zoölogical nature.

The theory which underlies the main choice of topics in physics is that the molecular theory and the explanation of heat as energy of molecular motion are fundamentally important and that the pupil ought, therefore, to be acquainted with them. One exercise each is devoted to sound, light, and levers. Therefore, the course begins with an experiment in diffusion of liquids in which the diffusion is so obvious that the blindest of the pupils cannot fail to observe it. Parallel with this or following directly upon it, is given an equally obvious experiment in osmosis. In both experiments the pupils are carefully guided into making accurate and complete observations. Only the most phlegmatic of them fail to be astonished by the behavior of the fluids in both cases. When they have recorded their observations they are asked to explain what must be the structure of the fluids concerned if they can mingle in this way. By far the larger part of the class will always be ready with statements to the effect that the fluids must be made of very small particles; that since they have evidently passed through openings in the osmotic membrane which cannot be seen even with the microscope, they must themselves be exceedingly small. To the question of how particles which were in one place happen to be now in another when no external force has been applied, hesitatingly or contemptously, according to the personality of the individual, comes the reply "Why, they must be moving." "How much of the time do you think they are moving?" "All the time," for they see the diffusion keeping up day by day. And so they are given a name for the tiny particles of their theories and for the motion of the particles.

Next come experiments in diffusion of gases and effusion of gases, whereby the pupils are constrained to draw similar conclusions as to the molecular structure of gases and by comparison with the experiments with liquids, they come to realize that lighter molecules move more swiftly than heavy ones.

A repetition of the experiment in effusion of gases is now made with this difference. Instead of a jar of hydrogen being

placed over the porous cup, a jar of air is placed over it, and it is observed that there is no change in the position of the liquid in the manometer. Then hot air is forced by means of a bellows through a hot iron pipe into the jar. The effect upon the fluid is similar to that when hydrogen is used. Evidently the molecules of hot air move more rapidly than those of cold air. Heat is obviously the only explanation of the increased rate of the molecular motion. Experiments with air thermometers follow. Then experiments to show the expansion by heat of solids. Here then is introduced visible reason for concluding that solids also are molecular in their construction. Heat of vaporization and evolution of heat in solidification are now discovered by appropriate experiments with water and snow. The value of these experiments depends entirely, it is needless to say, upon the care with which pupils are guided in their observations and reasoning, and upon the skill with which class discussions are controlled. Atmospheric pressure is a topic very naturally introduced into this work, and appropriate investigation of the topic is made. One exercise is devoted to demonstrating that sound is produced by vibrations, and one is devoted to such experiments with light and such discussions as will enable the pupils better to understand the functioning of the parts of the eye when they reach the work in physiology. An exercise is also given in the study of levers, applications of the principles being made in the physiological work.

In chemistry, oxygen, hydrogen, nitrogen, carbon, carbon dioxide, sulphur, phosphorus, and iron are studied at first hand. These substances are chosen because of their direct relation to life, and the part which they play in metabolism. The meaning of oxidation and combustion is discovered. By painstaking reasoning from the observations in the laboratory, in the discussions in the recitation room some conception of chemical action is obtained. The composition of the air is demonstrated by a series of experiments in which oxygen is withdrawn from the atmosphere by rusting iron, and carbon dioxide by caustic potash. The synthesis of water having been observed in the combustion of hydrogen, analysis by means of electrolysis is demonstrated.

Acids and bases are examined and two neutralizations are performed. In connection with this work equations are made use of.

Throughout the work in chemistry and physics the greatest care is taken not to suggest to the class the truths which the experiments are designed to demonstrate, in order that the pupils may discover them for themselves and in order that their conclusions may not be warped by preconceived notions. For instance, when the experiments in diffusion and osmosis are set up, and the records of the apparatus and manipulation are made, the space for the topic is left vacant. After the observations have been made and the conclusion drawn the class is asked to suggest a topic, and it is really very interesting to hear them give appropriate titles.

With equal care they are led to follow up inferences with experiments to prove whether their inferences are correct. For instance, when they discover that gases expand in response to heat, they are sure to infer that liquids and solids will behave similarly, and experiments are performed to test the truth of these inferences. Of course, in this particular problem the exceptions are noted in the discussion.

From the work in chemistry they pass naturally to food testing. The teaching of the tests for each foodstuff affords excellent opportunity for insisting upon the scientific method of inquiry. No test is accepted as a test till it has been tried with each kind of foodstuff.

The work with foodstuffs immediately precedes the ten weeks' work in physiology in which the work deals with foods and digestion. Their previous work in heat and oxidation now comes into play most beautifully. With these studies for a mental background, paragraphs on the value of food as fuel and of hemoglobin as an oxygen carrier are much more intelligible than they could possibly be otherwise. There are lessons in hearing and on the eye which are, of course, much better understood because of the work in sound and light given in physics.

While the study of digestion is in progress an interesting test of the pupils' ability to employ the scientific method of inquiry is made. Each one is furnished with a piece of cracker and the materials for making food tests. Then he is required to discover

and prove the action of saliva on starch, the only direction given being to allow the bit of cracker to remain a short time in the mouth. Most of the pupils think out all the necessary steps for themselves, alone and unaided. The rest, except the hopelessly stupid ones, are questioned until they see what steps in the proof have been omitted and then they finish the problems.

Some attention is paid to problems in sanitation. Cultures are prepared which show how prevalent bacteria are, what is the difference between tap-water and distilled water, unsterilized and sterilized milk, the importance of methods of dusting and sweeping which prevent the dust from being stirred up, etc. Also at this time they mount and observe with the compound microscope bacteria of decay and the bacteria in the nodules on clover roots.

The remainder of the year is devoted to a little work in zoölogy and much more in botany. The zoölogy is to be introduced this year for the first time, therefore we do not know yet how satisfactory the choice of subjects may be. Certainly there can be made a direct connection between mosquitoes and sanitation and mosquitoes and toads, and surely, the metamorphosis of the frog or the toad, and that of an insect are life-histories which should be common knowledge. The work in botany is correlated with the physiology by experiments which prove that the gas-exchange in respiration of plants is identical with that in animals, and by the study of photosynthesis, whereby they are made conscious of plants as the carbohydrate producers. The rest of the work in botany is to be conducted with a view to rendering the pupil able to tell whether a given plant which he may encounter is a moss or an alga, a fern or a flowering plant, and to start him on his way toward knowing by name, or at least recognizing the family of the flowering plants of his environment.

Of course, if a full year's work could be done, much could be accomplished in the way of applying the principles learned in practical ways. Such work could be planned which might be highly desirable. But in what is virtually a semester's work, no more can be crowded in, and all the theoretical work inserted in the course seems so necessary that we are unwilling to omit any of it for the sake of a few practical applications.

A textbook is used only in connection with the physiology. In the rest of the course the use of one would defeat our aims. We desire that the pupil shall solve the problems himself, shall learn to draw some conclusion from carefully obtained data, and shall gain his knowledge of phenomena by first-hand experience.

There is, it seems to us, no valid reason why this course should not be made a part of the work of the eighth grade, instead of being made to subtract from the time given to science in the high-school course, save that it must be given by teachers of thorough scientific training. Even in the high school where special science teachers are employed, there is great danger that the value of it may be spoiled by teachers who are too thoroughly specialists to enjoy doing such strictly elementary work. Moreover, if the course is to be of equal value with freshman algebra and freshman Latin as a disciplinary subject, the instructor must be one who is quite as much interested in watching a pupil's mind develop habits of scientific thinking as in driving home a few elementary facts. That it may be made of great value as a means of mental training we have not the slightest doubt. That the facts taught here constitute a body of knowledge which ought to be acquired in any common high-school education it would seem that no one could dispute. That some large part of them would not otherwise be acquired by the great majority of the graduates of our high school is a painfully indisputable fact; that many of them are not acquired by the graduates of the average high school in which there is no such course is equally true.

Moreover, to us who are watching the effect of this course upon the school, it is clear that this presentation to the pupils, while they are yet in the early part of their secondary work, of a unified introduction into the fascinating realm of scientific thought and discovery is having a wholesome effect upon their choice of studies, an effect which is helping to increase the size of our classes in advanced sciences despite the apparent lack of value placed upon secondary-school work in science by those bodies of men who determine the entrance requirements of our colleges.